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Specification and Drawings, as originally filed, with Application for Patent Serial No: **2,434,380**, on July 4, 2003, by **HOLCIM LTD.**, assignee of McQuiggan Thomas Lowes, for "Method and Apparatus for Gas Injection to a Kiln System".

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METHOD AND APPARATUS FOR GAS INJECTION
TO A KILN SYSTEM

FIELD OF THE INVENTION

[0001]   The present invention relates to a method and apparatus for introducing gas into a kiln system. More particularly, it relates to a gas injection system that entrains process gas flow causing mixing, facilitating the combustion and removal of gases present during combustion in a kiln system.

BACKGROUND OF THE INVENTION

[0002]   Kiln systems are known for processing cement clinker and various metallic and non-metallic minerals such as iron ore and lime. In this application, the text focuses on kiln systems for producing cement clinker, however, it will be understood by one of skill in the art that the concepts presented may have application in other types of kiln systems.

a)   DESCRIPTION OF CEMENT MAKING PROCESS

[0003]   Cement clinker is the material that, when finely powdered forms cement, which is mixed with water and inert materials to form concrete and mortar. Cement clinker is conventionally produced by heating raw materials to very high temperatures in a kiln system. There are various types of kiln systems known in the art, including wet and dry "long" kiln systems and various types of preheater kiln systems. The following discussion will focus on preheater kiln systems however, similar processes occur in and similar difficulties may also arise in long kiln systems.

[0004]   A conventional preheater kiln system used for the production of cement clinker generally consists of two sections, the preheater section and the kiln section. The preheating section consists of a gas riser duct and a series of cyclones, typically four or more in number mounted in a vertical structure, wherein the last cyclone in the series feeds into the kiln section via a feed chute.

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[0005]   The kiln section consists of an inclined rotary kiln, which provides primary heating for the kiln system. The inclined rotary kiln includes a fuel inlet and flame at its lower end for heating the kiln. In some preheater kiln systems there may also be a secondary firing system in the gas riser duct or a precalciner (which is also referred to as a calciner) , provided to calcine the majority of the raw material prior to entry to the kiln section. The precalciner may be provided between the preheating section and the kiln section but may also be a part of the preheater section.

[0006]   For convenience, it is common practice to use a pair of cyclones in parallel at the uppermost stage of the preheater, and for high-throughput systems, a single kiln may have a complete set of "twin" preheater cyclones in series, with one or both of these "preheater strings" provided with a precalciner furnace or secondary firing system(s).

[0007]   In a preheater kiln system, a mix of powdered raw material having the appropriate chemical composition ("raw meal") is fed into the uppermost cyclone. The raw meal used in the production of clinker in a conventional kiln system is conventionally prepared from natural quarried products that are principally comprised of limestone (a source of calcium carbonate), which is calcined to lime during heat treatment, with liberation of carbon dioxide via an endothermic reaction, and shale (a source of silicates, aluminates and iron oxide). When necessary, local reserves of raw materials are supplemented by corrective amounts of components such as sand (a source of silica), bauxite (a source of alumina), pyrites (a source of iron oxide) and /or limestone (often from higher purity reserves) to make up the raw meal. The raw material is finely ground and blended to form the raw meal before it is added to the uppermost cyclone.

[0008]   The raw meal provides a basic chemical mixture that, when calcined and combined with ash from fossil or alternative fuels in the kiln system, allows for the formation - in an alumino-ferrite flux - of a blend of calcium silicates and aluminates (called "clinker"). This is finely ground with addition of a set-control agent such as gypsum to form Portland cement, and when mixed with water, the silicates and

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aluminates undergo hydration reactions (i.e. set and grow in strength to produce concrete or mortar).

[0009]   When the raw meal is fed into the uppermost cyclone it is dispersed and pre-heated by a gas flow emanating from the next cyclone down in the series. Within each cyclone there is a vortex that disperses and collects the raw meal. The vortex facilitates the movement of the raw meal from the first cyclone to the second cyclone in the series. As the raw meal moves down the cyclones it heats up and may partly calcine and, if combustible material is present, some of it may combust, ultimately leaving a final mixture known as kiln feed. The vortex in each of the cyclones facilitates the movement of the raw meal down the series until it reaches the last cyclone. During the preheating stage, before the raw meal reaches the inclined rotary kiln, the temperature of the raw meal is raised to approximately 600 to 900 degrees Celsius (°C).

[0010]   Once the raw meal passes through the last cyclone, it reaches the kiln hearth and (now referred to as "Kiln Feed") moves into the upper end of the inclined rotary kiln via a feed chute. Upon entering the inclined rotary kiln, the kiln feed is known as hot meal. The hot meal progresses toward the lower end of the inclined rotary kiln in counter current to the gaseous products produced during fuel combustion at the lower end of the inclined rotary kiln.

[0011]   As described above, the inclined rotary kiln has a flame at the lower end of the incline (the "flame zone"), which heats the contents of the rotary kiln. The temperature of the hot meal is raised to approximately 1450 °C before exiting the lower end of the rotary kiln. At this temperature the hot meal reaches a semi-molten state in which chemical reactions take place, forming clinker. The flame and gas temperatures at the lower end of the inclined rotary kiln must be considerably higher than 1450 °C to ensure that the hot meal reaches this temperature.

[0012]   Once clinker is produced at the end of the inclined rotary kiln it flows into a clinker cooler where it is cooled by air. The hot air produced from the cooling of the clinker can then be reused to heat other sections of the kiln system, such as the

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preheater or the precalciner, in an effort to conserve energy. To move the hot air, the kiln system may be operated under negative pressure with exhaust gases being drawn through it under a draft induced by a fan. The fan may be located at or beyond the pre-heater exit.

[0013]   In the kiln system, gases travel up through the rotary kiln, gas riser duct and cyclones generally in counter current to the raw meal and may absorb many contaminants present. Prior to release to the atmosphere, the gases are typically dedusted to meet strict regulatory limits and if necessary are also cleansed of impurities such as NOx before release into the atmosphere.

[0014]   A development in conventional preheater kiln systems is that fuel combustion may also take place in the secondary firing system (as described above), by supplying appropriately prepared fuel to the gas riser duct. This practice increases the throughput of a kiln system while having little effect on thermal efficiency. In addition, it also raises the degree of decarbonation ("calcining") of limestone entering the inclined rotary kiln, in turn reducing the thermal load on the flame zone of the kiln and often reducing the volume of combustion gases flowing through the rotary kiln.

[0015]   In a further development, secondary firing may be extended to a greater degree in kiln systems fitted with a precalciner. A precalciner is an additional combustion vessel or furnace that is located at or near the base of the preheater where it is fed with appropriate fuel and air, preferably preheated. Preheated air for the precalciner may be taken from the exhaust produced from the clinker cooler, as described above. The preheated air can be moved by by-passing the rotary kiln in an "air separate" system, where it is practical to do so. Alternatively, the air may be received from the rotary kiln in an "air through" variant.

[0016]   Further advantages may accrue with the operation of a precalciner, similar to those described above for riser duct firing. One of the primary advantages is that the precalciner allows for a greater scope and selection of operating conditions, which in turn may allow for a reduction in the level of oxides of nitrogen (NOx) passing through

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the preheater to the atmosphere.

[0017]   Another variation of a conventional kiln system includes the use of a grate preheater system, commonly referred to as a "Lepol grate". Here, a finely ground raw meal mixture is formed into nodules /pellets by the addition of water to a rotating inclined dish. The pellets are then fed to the end of a travelling grate where they are swept by the kiln exhaust gases in order to be dried and preheated. Supplementary firing may be done in and after the gas riser duct connecting the upper end of the kiln to the hot end of the grate, known as "over grate firing". This process has benefits and problems analogous to those that are described for the cyclone pre-heater systems and stratification of gases from combustion in the various parts of the kiln system.

[0018]   Clinker production makes intensive use of natural resources, both in terms of energy and raw materials. Due to the natural origin of the raw meal/kiln feed and fuels used in a kiln system, minor amounts of other chemical species may also enter the kiln system. These other chemical species can enter in quantities that adversely influence conditions within the kiln system. Furthermore, kiln systems produce an exhaust gas stream that requires cleaning to ensure that any potentially harmful chemicals that may be produced during the process are reduced in concentration before the gas stream is released into the external environment and atmosphere.

[0019]   Manufacturers are concerned with reducing their impact upon the environment. For example, use of prime reserves of raw materials and conventional fuels can be reduced by reducing the consumption of energy derived from fossil fuels. One way to reduce the use of prime reserves is by using alternative raw materials and /or alternative fuels, such as by-products of agricultural, process and commercial enterprises. These alternative substances can play a dual role in a kiln system. Some of the alternative substances used as partial replacements for raw materials may bring a fuel content with them and some alternative fuels may bring a significant content of ash, and as such play a dual role as both of these are required in a kiln system. A consequence of using alternative substances in lieu of traditional ones, however, can be that additional organic matter and carbon may be present for combustion in regions of

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the system other than the expected combustion in flame zones.

[0020] A drawback to the use of either a conventional or an alternative fuel (before processing "raw fuel"), is often the need for prior expensive and energy-intensive preparation, examples of such would be the fine grinding of solids or the atomisation of liquids. Accordingly, there is a desire to use fuels effectively in the process and minimise the preparation required. Alternatively, there is a further trend underway to use fuels that are more difficult to burn (due to their hardness, moisture content or adhesiveness) as long as undue additional expenses are not incurred in preparing them, and provided their dispersal and maintenance in a suitably oxidising gaseous medium (as required by their combustion characteristics) is maintained. By way of example, this trend can be seen in the techniques set out in various patents that deal with the introduction of used vehicle tires into the upper end of long kilns that are not generally equipped with preheaters. An example is US Patent No. 5,078,594, issued to Cadence Chemical Resources, Inc. and Ash Grove Cement Company.

[0021] The benefits of using alternative materials and fuels include reducing demands upon prime reserves and eliminating the problem of otherwise disposing of wastes and by-products and the attendant effects upon the environment.

[0022] Kiln systems are well suited for the use of various low-grade combustible coarse or lump fuels, because the ash can be assimilated within the clinker product. The reason for this is due to the fact that combustion occurs under controlled and high temperature conditions, with significant residence times for fuel particles at these temperatures.

DIFFICULTIES IN THE OPERATION OF CONVENTIONAL KILN SYSTEMS

[0023] Various difficulties arise in the operation of conventional kiln systems, including pre-heater kiln systems when using either traditional fossil fuels prepared according to conventional methods and /or alternative fuels prepared by less conventional means.

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[0024] As a consequence, there may be limitations on the amount of one or more fuels, in a given state of preparation, that can be supplied to a precalciner, gas riser duct or upper end of a kiln while still maintaining suitable clinkering conditions at the lower /outlet end of the kiln system.

[0025] Conventional preheater kiln systems may have one or more of the following difficulties: (a) a build-up of solid material in the system resulting in either a partial or complete blockage; (b) an increased generation of one or more pollutants, such as NOx (or a limitation upon the degree of abatement possible within the process); (c) an increase in energy consumption per tonne of product; and/or (d) a reduced output rate.

[0026] Several of the above noted difficulties have the additional disadvantage of limiting the possibilities for reducing consumption of prime fossil fuels with a consequent accompanying limitation of the scope for reducing the generation and emission of greenhouse gases, such as carbon dioxide. Some of the difficulties can, in principle, be alleviated by more intensive pre-treatment and preparation of the fuel, in addition to using more complex procedures for its controlled delivery in the process. Implementing such solutions, however, is often not cost-effective.

[0027] Ideally, when more fuel energy is put into some part of the kiln system, such as a preheater gas riser, which is downstream with respect to the combustion products, of the main burning zone, the result should be an increase in solid throughput where there is either no change or only a small change in the temperature of the gases emerging from that part of the kiln system. Higher exit gas temperatures would suggest that the extra energy has not all been efficiently applied to heat the solid materials, but has instead been wasted in creating and heating the gases.

[0028] Techniques intended to promote the beneficial mixing of gases in kiln systems are known, however, the levels of momentum and swirl involved are typically not large enough to be completely effective aerodynamically. Accordingly, the techniques that can have the most advantageous effect on the flow of gases and on heat transfer to and from the fuel and feed particles are not present in the parts of the

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process where they can best contribute to solving the problems that arise with respect to completion of combustion and other chemical reactions in kiln systems.

SUMMARY OF THE INVENTION

[0029]   It is therefore an object of the present invention to provide an improved apparatus and method for gas injection to a kiln system addressing at least some of the problems identified above.

[0030]   In particular, an embodiment of the invention relates to an apparatus and method for adding or injecting suitably-directed high momentum swirling turbulent air to dust-laden stratified combustion gas at approximately 850 to 1400 °C to eliminate stratification and improve mixing of both gases and suspended solids. The injection of air serves to enhance the contact of reacting materials, such as residual fuel and available oxygen, and further serves to improve the completion of reactions, such as combustion of the fuel and the transfer of heat to the raw material/kiln feed.

[0031]   The projected benefits of the embodiments of the invention include increased fossil fuel substitution, lower carbon monoxide emissions lower emissions of oxides of nitrogen, ammonia and dioxins, higher levels of petroleum coke use and increased clinker output.

[0032]   The mixing provided by the gas injection results in the improved combustion of lump solid fuels (such as tires, wood and plastics) to encourage full, controlled and non-polluting combustion with energy release. The mixing provided by the gas injection also improves gas-to-particle heat transfer and makes better use of available oxygen in a kiln system.

[0033]   Other aspects and features of the present invention will become apparent to those of ordinary skill in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying figures.

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BRIEF DESCRIPTION OF THE DRAWINGS

[0034] The embodiments of the present invention shall be more clearly understood with reference to the following description of the preferred embodiments and to the drawings, in which:

[0035] Fig. 1 illustrates a preheater kiln system;

[0036] Fig. 2 illustrates a swirl air system located in a precalciner between the tertairy air and fuel entries, according to an embodiment of the invention;

[0037] FIG. 3 illustrates a cross-sectional top view of the swirl air system of Fig. 2;

[0038] FIG. 4 illustrates a cross sectional side view of the of Fig. 3;

[0039] Fig. 5 illustrates a cross-sectional top view of a swirl air system comprising two concentric contra-rotating swirl vortices according to another embodiment of the invention;

[0040] Fig. 6 illustrates a cross-sectional side view of the swirl air system of Fig. 5;

[0041] Fig. 7 illustrates a cross-sectional top view of a swirl air system comprising two concentric contra-rotating swirl vortices according to another embodiment of the invention;

[0042] Fig. 8 illustrates a portion of a preheater kiln system including the swirl air system of Fig. 7;

[0043] Fig. 9 illustrates an injector for the swirl air system of Fig. 7;

[0044] Fig. 10 illustrates a kiln system indicating two possible locations for swirl air systems according to embodiments of the invention;

[0045] Fig. 11 illustrates a portion of a kiln system including a swirl air system according to another embodiment of the invention;

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[0046] Fig. 12 illustrates a preheater kiln system with secondary firing supplied to the gas riser duct illustrating including two possible locations for a swirl air system according to embodiments of the invention; and

[0047] Fig. 13 illustrates an air-separate calciner kiln system including two possible locations for a swirl air system according to embodiments of the invention.

DETAILED DESCRIPTION

[0048] Figure 1 illustrates a typical preheater kiln having a preheater section and a kiln section. The preheater section includes a raw meal feeder, which feeds raw meal to the uppermost of a series of inter-connected cyclones through which the raw meal passes, a gas riser duct which transports gases from the kiln section to the lowest cyclone, and a feed shelf or kiln hearth, which is connected to the lowermost cyclone, and includes a chute which connects the preheater section to the kiln section. The kiln section includes an inclined rotary kiln which is connected via a seal to the kiln hearth at the upper end, a fuel feed which is provided at the lower end of the rotary kiln and provides fuel to heat the interior of the rotary kiln, and a clinker cooler which is connected via a seal at the lower end of the rotary kiln near the fuel feed.

[0049] In operation, raw meal travels via the raw meal feeder and enters into the first of the series of cyclones. The raw meal is collected from the cyclone by vortex action and travels into a duct that is connected at the base of the cyclone (or cyclones, should their be a pair) and then proceeds to enter a subsequent cyclone for redispersal into the gas stream and collection, until the raw meal reaches the feed shelf by the action of gravity and of the cyclones. At the same time that the raw meal is travelling through the preheater section by gravity, hot gases from the kiln section are rising through the gas riser duct and through the cyclones in a generally reverse direction to the flow of raw meal. As such, the raw meal is heated as it is dispersed at each stage in the hot air and gases coming from the cyclone below or via the gas riser duct from the kiln section or (if fitted) from the precalciner, as described in more detail below.

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[0050]   The hot raw meal then enters the kiln section at the upper end of the rotary kiln where it continues to travel through the rotary kiln by gravity and by the rotation of the rotary kiln, provoking a mixture of sliding and tumbling. The raw meal continues to be heated throughout this process and eventually reaches the lower end of the rotary kiln where it is discharged into the clinker cooler and cooled by a flow of air. This air flow is typically used in other parts of the kiln system to make use of the heat contained in the air following exposure to the clinker.

[0051]   In this conventional preheater kiln system, additional fuel may also be added into the gas riser duct or onto the feed shelf of the preheater section to provide further preheating of the raw meal prior to entry to the kiln section. Some fuel may also be added directly to the upper end of the rotary kiln, e.g., used tires

[0052]   In a kiln system, the burning of fuel and the chemical reactions occurring in the raw meal result in the release of various chemical species into the gas flow within the kiln system. Minor chemical species in a kiln system include compounds involving elements such as chlorine, sulphur, sodium, potassium along with other elements within the same families. These are volatilised to a greater or lesser extent in the hotter regions of the kiln system and are carried in the gas stream to colder regions where they condense and where they may form solutions with low melting points. The volatile species may then bind particles of solid feed material together and bind to the ductwork in the kiln system. This process can lead to partial and/or major blockages and as a result the kiln system will require cleaning or other intervention to maintain the proper output.   In some situations a permanent set of air blasters can be installed to curtail the problem of blockage.

[0053]   Having condensed, some of the volatile species that do not bind to the ductwork travel down to the hot regions in the kiln system again and undergo the volatilisation process again. The cyclical pattern increases the concentrations of volatile species and aggravates the attendant problems.

[0054]   The degree of volatilisation of the compounds may be affected by the

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following: (1) the composition of the local gaseous atmosphere; (2) coming into contact with other chemical species in the bed of solids; (3) the temperature of the kiln system; and /or (4) the behaviour upon condensation. For example, the decomposition of calcium sulphate is affected by concentrations of oxygen and carbon monoxide, by contact with solid carbon, and by temperature. The decomposition of calcium sulphate can have unfortunate consequences when the amount of sulphur entering the kiln system is greater than that which can enter into combination with available (non-halide combined) alkalis as alkali sulphates. When this happens, the excess sulphur tends to react to form calcium sulphate or calcium-potassium-sulphate otherwise known as "calcium langbeinite" which are liable to decompose and volatilise as local conditions vary. It is preferred that the sulphur leave the kiln with the clinker product in a stable chemically combined state, rather than decomposing, volatilising and aggravating the recirculation, build-up and blockage phenomena.

[0055] Under certain conditions, halide species can be precursors in the formation of organic pollutants. Such conditions may exist when there are traces of organic impurities liberated from the raw materials and fuel being preheated. If suitable conditions of temperature, residence time and concentrations of chemical species exist, undesirable pollutants could then form and potentially be lost into the atmosphere once they condense onto dust or fume.

[0056] When oxidising gases are not readily available, residual carbon ("char") from traces of solid fuel within the raw material components or from coarse or lump fuel used in secondary or precalciner firing may sometimes persist throughout the pre-heater and enter the inclined rotary kiln. The combustion of the residual char may then produce local reducing conditions for sulphates, aiding in volatilisation and inhibiting condensation. To avoid this occurrence attempts have sometimes been made to operate the kiln system with a higher level of excess air than otherwise required. The extra air aids in the combustion of char but leads to energy losses due to the heating of the nitrogen in the extra air. This adversely affects the potential for clinker output where output is limited by the capacity of the induced draft exhaust fan that follows the pre-

heater. Inadequate combustion in a secondary firing system or precalciner can also be a source of residual char passing into the rotary kiln.

[0057]   Gas riser duct firing typically does not achieve useful gains in kiln throughput unless there is adequate heat transfer to the solid material being processed. In practice, this is seen for firing up to approximately 10 to 15% of fuel in kiln systems where kiln fuel replacement by good quality pulverised coal or oil at the secondary firing stage is used. When gas riser duct firing is implemented, higher excess air levels may need to be used to deal with other "difficult" low-volatile fuels such as petroleum coke (known as "petcoke"). The higher excess air levels here work to ensure complete combustion while keeping the probability of build-up acceptably low, but, as discussed above, bring a wastage of energy in heating the larger quantities of nitrogen in the extra air, as well as loss of kiln output rate.

[0058]   In addition to the above, when lower grade fuels are used, extra air also needs to be passed through the kiln system resulting in a reduction of the temperature of the main flame. Accordingly, some or all of the extra energy will not be transferred to the raw material and raw fuel, which in turn results in a higher volume and temperature of exhaust gas being handled by the induced draft fan. If the draft fan lacks the capacity to cope with the required new duty, it may further present a bottleneck in the kiln system with respect to increased output rates. In this situation, transient carbon monoxide peaks may also be seen due to fuel quality or feed rate variations, resulting in a generally higher level of carbon monoxide emission from the system.

[0059]   Carbon monoxide resulting from incomplete combustion will tend to rise toward the uppermost layers of gas within the rotary kiln, and it will not be positively mixed to react with the residual oxygen present. Conversely to carbon monoxide, carbon dioxide tends to be more highly concentrated near the solid bed in the rotary kiln. Upon leaving the rotating kiln section, stratification of the gas may persist into lower regions of a preheater and riser duct firing system. The stratification does not help the rapid complete combustion of raw fuel and more particularly lump fuel added at the kiln feed chute or where it is allowed to fall onto the kiln bed at its upper end, which

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is sometimes the practice for materials such as used tires.

[0060] Volatile chemicals liberated from a lump fuel as it ignites and burns typically do not have the opportunity to react with all the traces of oxygen present until later mixed in the preheater or calciner system. This often occurs at lower temperatures and as a result, traces of volatile hydrocarbons can sometimes emerge into the atmosphere as undesired pollutants. The undesired pollutants may also be accompanied by higher than desired traces of unburned carbon monoxide. As described above, the conventional solution is to operate the kiln system at a higher level of excess air. This too has potential drawbacks that may function to limit the quantity of lump fuel that can be added at the upper end of the kiln. A possible solution is to enrich the oxygen content of the combustion air (rarely an economic proposition) and /or to undertake major and costly reconstruction and enlargement of the hearth area at the pre-heater exit (if feasible) with an attendant loss of production during the modifications.

[0061] Another drawback in using lump fuels is that they can limit the potential of use of high-sulphur fuels in the process, such as petroleum coke ("petcoke"), due to their influence on the decomposition, volatilisation and deposition of sulphates. Such petcoke is often cheaper to obtain due to difficulties in using the petcoke in boilers and processes that do not inherently absorb the extra sulphur.

[0062] There is a need to achieve a more complete and uniform burnout of char, carbon monoxide and volatile material from "difficult" alternative fuels and to avoid operating kiln systems at unduly high and wasteful levels of excess air that may impair throughput. Here, "difficult" refers to the idea that virtually all alternative fuels have one problem or another, either due to residual carbon due to initial size or/and lack of volatile matter (tires, wood chips, petcoke), sudden volatile release due to either feeding (e.g., whole tyres or bags/bales of commercial waste) or to high volatile contents (e.g. drill cuttings), or slow burnout (e.g., palm kernel shells, petcoke). Furthermore, it is possible that carbon dioxide concentrations in the boundary layer of gas around the raw meal and fuel in a precalciner may be high, as well as high carbon monoxide levels in the gases surrounding the fuel particles, given the gas flow and turbulence conditions

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that normally prevail. High carbon dioxide or carbon monoxide concentrations may require operating the calciner at temperatures that are higher than ideally desired from the viewpoint of throughput and material reactivity. Residence times for effective mixing and combustion in many existing precalciners are not sufficient to allow for the oxidation of all the carbon in slow burning solid fuels. By increasing the temperature in the calciner it will also increase the exit temperature and change the location of regions where volatiles condense, often to non-accessible areas.

[0063] Stratification of gas composition can arise within ducts emerging from a precalciner and in a precalciner itself. Inadequate mixing in a precalciner vessel can lead to an increase in the temperature of the gases emerging from the vessel for an apparently unchanged level of calcination of the raw feed. This is the average result from a non-uniform mix of over-calcined and /or under-calcined material that eventually may adversely affect clinkering reactions as well as patterns for deposition of sulphates.

[0064] As a result of stratification, attempts to reduce the concentration of nitrogen oxides ("NOx") via reburning reactions involving fuel injection at suitable process zones may fail to achieve their full potential, again leading to possible undesired and unnecessary emissions. The NOx reburning reaction involves the introduction of fuel and volatiles to a gas stream deficient in oxygen at a temperature between approximately 1000 to 1400 °C. The reaction is more efficient at higher temperatures and lower levels of local stoichiometry.

[0065] Another method to reduce NOx is by using a staged combustion. This is achieved by allowing sub-stoichiometric combustion of fuel volatiles, then afterwards introducing the remaining oxygen to complete the combustion, serving to reduce the concentration of NOx formed from the "Fuel NOx" reaction. Appropriate mixing of the solid and gaseous components in the reaction is advantageous, both before and after staging.

[0066] For the further abatement of NOx, a Selective Non-Catalytic Reduction ("SNCR") method can be used with the injection of appropriate amounts of ammonia or

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ammoniacal compounds (or solutions of these) at a suitable temperature and in the presence of a certain range of oxygen concentration, as this gas is involved in the chemical reaction as set forth:

$$2NH_3 + 2NO + 0.5O_2 \Longleftrightarrow 2N_2 + 3H_2O$$
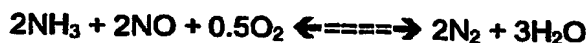
[0067]   The active component is the $NH_2{}^*$ radical, which may also be provided by alternative reagents. Theoretically, the optimum temperature range for efficient reduction is between approximately 850 to 1050 degrees Celsius. In practice, it is not always possible to assure suitable complete reaction of the injected ammonia by guaranteeing sufficient residence time for the reacting molecules at the appropriate conditions of gas temperature and composition. A consequence will be the emission to atmosphere of undesired traces of ammonia and/or a failure to get the emission level of oxides of nitrogen down to the desired level. The ammonia emission presents a double problem in that it may both infringe operating permits and lead to the formation of a dark-coloured plume above the chimney stack. This arises as the emitted gases cool, through formation of a fine fume of ammonium salts (usually sulphate or chloride) that is very effective at scattering light.

[0068]   It has also been observed that the use of fuels that are difficult to burn in secondary firing systems, such as lump coal, or of fuel that is incompletely burned in the calciner, can be associated with the detection of dioxins and/or furans in dust from exhaust gas by-pass systems (in which a proportion of the gas stream is extracted, cooled and de-dusted to removed condensed volatile compounds). This is attributed to unburned fuel, such as carbon or volatiles, being carried into the by-pass and acting as drivers for the *de novo* dioxin synthesis reaction. It is desirable to prevent such carry-over and use the fuel energy productively.

[0069]   There are a variety of geometrical designs of preheaters (including ducts and cyclones) and precalciners that may be connected to an inclined rotary kiln. The use of any specific variant in these descriptions is not intended to limit the embodiment of the invention, but merely to indicate general principles that can be applied to resolving

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problems in a kiln system. The same is true for the range of fuels that may be used and methods of fuel preparation and delivery to the kiln system. Additionally, although descriptions are generally made on the basis of a symmetrical disposition of equipment, practical difficulties may sometimes prevent this from being achieved at a given location, and in such circumstances appropriate adaptations may be needed. Again, these variations are not intended to limit the scope of the invention.

[0070]   As will be evident from the following text, it is useful to examine and attempt to overcome some of the problems in conventional kiln systems through fluid dynamics.

[0071]   A swirling air system ("SAS") according to an embodiment of the invention will first be described generally and will then be described in more detail. Generally speaking, a SAS according to an embodiment of the invention will involve the following considerations. Without prejudice to the scope of later descriptions, a typical SAS may include:

- a single injector placed on the axis of the kiln system, pointing in the direction of process gas flow, possibly with a bluff body and/or a swirl vane (an "axial SAS"), in one example a SAS may be axially located towards the upper end of the rotary kiln, where the gas temperature is approximately 1200C (an "axial kiln SAS"); or
- multiple injectors with swirl vanes injecting across the process gas flow, which can be angled towards a specific central or tangential location, to create an initial free vortex that decays with further turbulent mixing to a Rankine vortex (a "peripheral SAS"), in one example such a SAS may be in a gas riser duct or precalciner or the like (a "preheater SAS", "gas riser SAS" or "precalciner SAS").

[0072]   Typically the details of each SAS design will be process and plant specific but are preferably based on the rules of fluid dynamics for jet entrainment. Each SAS is designed using jet entrainment equations to generally provide that:

- For the axial kiln SAS option, all of the gases generated downstream of the SAS are fully entrained into the jet flow before the new plug flow region
- For the peripheral SAS, involving gas injection at or near the vessel wall in the kiln/ gas riser/ calciner/ by-pass, the relative proportion of all the gases are entrained into each jet before their meeting point in the central toroidal vortex for more mass and heat transfer (e.g., a quarter of the gas flow for each one of four injectors).

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[0073]   As an example, the fluid dynamics equation used may be:

$$Mj/Mo = [K1 (K2 +K3{}^{*}S)^{*}x]/[do^{*}(Tf/To)^{1/2}]$$

Where:

Mj, Mo – total mass in jet at distance x, initial mass in jet
K1 – constant, depending on size of bluff body and degree of cross flow, range 1 to 1.4
K2 – constant – 0.35 (experimentally derived)
K3 – constant – 4 (experimentally derived)
S – swirl number of the injector
x – axial distance
do – effective injector diameter
Tf – temperature of fluid to be entrained
To – temperature of the jet fluid.

[0074]   The actual design calculation for specific embodiments of the SAS may alternatively be determined using computational fluid dynamics ("CFD") techniques. However, at the time of writing, CFD is probably only of value for comparing the effects of possible changes to the geometry or operation of an existing system because CFD may not be able to predict or model swirling flows as well as the application of the above equation due to the current inadequacy of turbulence models available for strongly swirling fluid flows.

[0075]   The SAS is provided to inject a high momentum, swirling turbulent stream of air (or other gases) into a stratified combusting gas and particle flow at approximately 850-1400 °C in a kiln, gas riser, precalciner, or the like, in order to remove the stratification and improve combustion and gas-to-particle heat transfer, making better use of available oxygen. The additional air – usually with a momentum level similar to that of the main process gas flow – arrives via injector(s), designed specifically for the plant concerned, which may each include swirl vanes and/or a bluff body.

[0076]   For typical process gas flows:

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- The Reynolds number, which indicates turbulent flow and mixing, is expected to be approximately 2.5 times higher at some $7.5*10^6$ than in a typical main process gas flow, hence increasing turbulent mixing
- The minimum eddy size is expected to be approximately 50 times smaller, that is, to less than the size of particles of pulverised coal and raw material (around 3 microns), hence increasing heat transfer for both combustion and calcination
- The turbulent frequency, which indicates the rapidity of eddy fluctuations, is expected to be increased by approximately 100 times or more from $1.5*10^5$ sec-1 to $5*10^7$ sec-1, again facilitating mixing, combustion and heat transfer
- The jet entrainment and mixing due to the bluff body and swirl vanes is expected to be approximately 2.5 times higher in a specific distance than for injection without swirl at the same velocity, hence the amount of air and fan pressure can be lower for the same effect and give a more beneficial impact on both the installation and the process.

[0077]   It should be noted that normally, in cement kiln systems, values of Reynolds number, eddy size and turbulent frequency such as the above are found only in the main kiln flame zone.

[0078]   Figure 2 illustrates a SAS according to an embodiment of the invention. The SAS may be applied to a gas riser duct, to a precalciner, or to a rotary kiln in a kiln system. The SAS includes one or more injectors directed into the kiln gas stream that is flowing through, for the example of Fig. 2, the gas riser duct or the precalciner. In Figure 2, the embodiment of the SAS illustrated includes four injectors that are directed tangentially to a 0.3R circle representing approximately 10% of the area through which kiln gas flows.

[0079]   In this embodiment, gases are injected tangentially at a high momentum level to eliminate the stratification of gases at temperatures ranging between approximately 850 to 1400 °C. This embodiment of the invention also improves combustion, other chemical reactions and heat transfer to the solids, such as raw material and raw fuel in the kiln system. An important factor in eliminating gas stratification which can lead to other improvements, is to achieve jet entrainment of the majority of the process gas stream (preferably over 80% and ideally 100%) into a new flow pattern in which turbulence is enhanced and predominates, at temperatures favourable to the chemical

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reactions. The concept is to create a jet mixed free vortex flow of all the process gases
that then decays with further turbulent mixing to an intermediate vortex. The direction of
gas injection is preferably neither directly axial nor directly orthogonal to the flow
direction of the process gas stream. The gas injection is preferably aimed tangentially
from several injectors to one or more virtual circles centrally located within the flowing
gases. The virtual circle(s) should cover at least approximately 5% of the cross-
sectional area of the process gas flow at the region of injection. The injected gas may
be air or oxygenated air, perhaps preheated and optionally directed at an angle of up to
approximately 60 degrees to the axial direction of gas flow. Additionally, the gas
injection may be carried out via tubes or nozzles optionally fitted with swirl vanes at
approximately 10 to 35 degree angles and/or via flare diffusers or bluff bodies at
approximately 5 to 20 degree half angles.

[0080] As will be understood by one of skill in the art, suitable materials for the
construction and the protection of the injection module(s) in the kiln system must be
considered, for example, steel alloys and/or refractory ceramics that are able to
withstand high temperatures are desirable. Internal self-cooling systems can also be
included.

[0081] It may also be advantageous to include suitable mounting systems to facilitate
the maintenance and cleaning of the injection module in the kiln system. For example,
cleaning mechanisms may be added to dislodge any build-up of chemical species,
process fume and /or dust that may adhere to a portion of the SAS inside the kiln
system. Further, where injectors do not protrude far into the process gases and have
openings close to the interior lining of the process equipment, it may be necessary to fit
traps for solid particles along with an automatic means of removal of the trapped
material.

[0082] It will also be understood that the SAS may have one fan or blower (i.e.
source of air) per injector or one source of air per several injectors. The injected gases
are preferably re-used from other parts of the kiln system or other parts of the cement
making process, where available.

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[0083]   As a general guide, the gas momentum required for proper mixing of gases is between approximately 50 and 150 percent (%) of the process gas flow. In order to minimise the amount of False Air injected into the system the velocity should be as high as possible, with a lower limit of approximately 150 m/s and preferably sonic or above. As a general guideline the approximate design criteria for SAS is a momentum around 10 N/MW and the capability to entrain up to about 15 times the jets own mass before reaching the centre of the process gas stream (for injection at or near the walls of the process vessel) or reaching the walls of the kiln (for injection on or near the axis). This involves a similar level of mixing energy to that used in a high momentum pulverised fuel burner for a kiln or boiler. Preferably, the injection should be at sonic velocity or above, if possible, and will be commensurate to the available fan pressure. A more detailed SAS design is based on the jet entrainment laws for swirling flows and bluff bodies, that take into consideration individual kiln, calciner, preheater, etc. geometries and mass flows and is aimed at achieving complete mixing via entrainment of the relevant process stream, before relevant impingement points either with the rotary kiln or other jet streams.

[0084]   Preferably, directing the injected gases from several points towards the circumference of a circle occupying approximately 10% of the central gas flow area will generally create a central mixing vortex. Adding a weak axial swirl to the injected gases will further enhance mixing, while avoiding the creation of an internal recirculation zone. For the mixing vortex, a net exit velocity of above 150 m/s is preferred. For the most advantageous effect, the gases should be injected at openings flush with the walls of the kiln system so that they may traverse the maximum possible path length within the process gas stream. Some protrusion of the injectors may, however, be desirable to avoid blockages in situations where solid particles could enter the tubes if they are not kept out by the aerodynamics of the incoming gases or where there are external obstacles that make it impractical to have long straight lengths of injector tubing outside the region of the kiln system concerned.

[0085]   An alternative or supplement to swirl vanes could be a bluff body, a centrally

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located solid disc or cone near the exit of an injector of slightly smaller maximum diameter to the orifice, which aids in both the internal recirculation and jet expansion and the effective entrainment, as well as facilitating the mixing of the main gas flow.

[0086]   Figures 3 and 4 show alternative arrangements of this embodiment of the SAS, in which swirl vanes are included within the injectors.

[0087]   Alternatively, in another embodiment of the SAS according to the invention, two concentric contra-rotating swirl vortices may be created by sets of injectors directed to the circumferences of two different virtual circular areas in the process gas stream. Figures 5 and 6 conceptually illustrate a SAS according to this embodiment of the invention. In this case, a set of injectors may be aimed at a smaller diameter circle located upstream in the process gas flow, so that an internal vortex can develop prior to penetrating a larger diameter contra-rotating vortex as it expands to engulf the outer peripheral process gas flow. This will create both intense central mixing and extreme turbulence at the vortex boundaries. Swirl vanes may be optionally used in the injectors to create yet further turbulence and bluff bodies may also be added.

[0088]   Figures 7, 8 and 9 illustrate a SAS according to this embodiment of the invention, Figure 7 being a cross-sectional view. Figure 7 shows a precalciner that is circular in shape and includes two coal lines for feeding fuel into the precalciner body. A SAS is provided to the precalciner and includes a set of four injectors directed tangential to a virtual circle located at the center of the precalciner and covering approximately 10% of the area of the process gas flow. These injectors induce rotational motion of the process gas flow travelling through the precalciner. The SAS further includes a set of two injectors directed tangentially at a second virtual circle at the center of the precalciner that is approximately twice the area of the first virtual circle and offset axially along the direction of process gas flow by a distance of approximately one precalciner radius from the first virtual circle. These two injectors are arranged to induce contra-rotating swirling of the process gas flow to the swirling produced by the set of four injectors.

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[0089]   Figure 8 shows an elevation of the precalciner showing that the injectors are directed at an upward angle of approximately 30° in this particular embodiment.

[0090]   Figure 9 illustrates an injector assembly included in the SAS of this embodiment of the invention. The injector assembly includes a valve, a pressure sensor and an injector which extends through the precalciner wall. In particular, there may be some benefit from having the injector outlet flush with the inside of the precalciner wall. The injector assembly may also include an inlet for compressed air to purge the injector of any potential blockage or the like. As discussed above, depending on the embodiment and the type of kiln system, the injector may also be provided with swirl vanes or a bluff body (not shown) to further enhance the formation of turbulence.

[0091]   By way of exemplifying the principles involved, consider the set of chemical reactions involved in NOx reburning where a preheater of a kiln system with a 2000 tonne per day rating has NOx emission from the kiln to the preheater of 1200 ppm. If the stack emission from the kiln system is to be below 500 mg/Nm3 (corrected to a 10% oxygen concentration, dry basis), part of the solution is to reduce the kiln generated NOx significantly. In this example 20% secondary fuel is added to the process gas stream that has emerged from a primary flame operating at 10% excess air level. The resulting stoichiometry will be 0.85, which is close to the optimum level of 0.88 for NOx reduction in a 0.5 second residence time at a temperature of approximately 1200 °C or more preferably 1300 to 1400 °C. To ensure intimate contact of the chemical species involved after the reburning reaction, the SAS can inject air to bring the stoichiometry up to 110% and ensure effective oxidation of carbon monoxide and residual hydrocarbons.

[0092]   The process gas flow rate for approximately 10% excess air can be calculated from the fuel consumption and carbon dioxide loss from the calcined raw fuel. The process gas velocity at a given temperature can then be assessed for a given duct diameter giving its momentum. If this is used as the target total SAS momentum, a minimum required injection velocity can be assessed from the additional air quantity

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needed to reach the 15% overall excess air supply if an injected air temperature of 20 °C is assumed.

[0093]   Figure 10 illustrates the application of embodiments of a swirling air system to a rotary kiln and/or to a gas riser. In some cases, it may be useful to have the SAS in both the rotary kiln and in the gas riser, for example, when trying to use whole used tires in a reburn reaction, a kiln SAS can help avoid build-up problems and a gas riser SAS can help bring in the extra air to avoid CO formation. If the swirling air system is applied to the rotary kiln it is preferably placed in an area where the gas temperature is approximately 1200° C. Figure 10 shows an axial kiln SAS and Figure 11 shows the axial kiln SAS in more detail. As shown in Figures 10 and 11, to avoid possible problems with blockage of injectors located flush with the internal lining of the rotary kiln (i.e. a peripheral SAS), the swirling air system may involve a single nozzle which is placed centrally in the rotary kiln and is directed in the same direction as the process gas flow (opposite in direction to the raw meal). In this case, the injector is provided with 30° swirl vanes plus a bluff body and the injected air is provided with enough momentum to entrain as much as possible of the main process gas flow before the impingement point at the kiln wall. This helps to ensure that the carbon in the process gas flow is burned out and allows avoidance of high sulphate-based build up in the kiln system.

[0094]   As shown in Figure 10, the swirling air system may also be applied in the gas riser duct. In this case, a peripheral SAS is used in which tangential injectors are provided and are directed such that they are tangential to a 0.3R (10% area) virtual circle in the center of the process gas flow within the gas riser duct. Further, the injectors may be inclined at an angle of 0° to 45° pointing upward in the direction of the process gas flow. This arrangement allows for reburn of NOx or CO to help eliminate or reduce these gases.

[0095]   Figure 12 illustrates the location of a kiln SAS or gas riser duct SAS in relation to the overall structure of a preheater kiln system.

[0096] Figure 13 illustrates the location of a kiln SAS or calciner SAS in relation to the overall structure of an air separate precalciner kiln system. In Fig. 13, the kiln system includes a tertiary air duct which takes heated air from the clinker cooler area to the precalciner and thus is referred to as an air-separate precalciner kiln system.

[0097] The SAS is intended to assist in overcoming typical combustion-related difficulties as follows:

- Reducing the impact of lump fuel on sulphate-based build-up in gas riser ducts
- Facilitating the use of petcoke with Alternative Fuels such as tyres or other lump fuels
- Reducing the level of CO and temperature produced at the exit of gas risers and calciners when both conventional and alternative fuels are used
- Reducing NOx, via reburning and/or staged combustion
- Reducing ammonia "slip" in the SNCR de-NOx procedure
- Reducing the amount of trace Dioxins or Furans formed in a by-pass

[0098] The SAS is intended to provide the following benefits in a kiln system (not necessarily all at the same time):

- Increased use of more (or coarser) alternative fuels
- Increased use of alternative fuels at the same time as petroleum coke
- Substitution of more coal or oil by petcoke
- Lower CO emissions with alternative fuels
- Lower NOx
- Higher clinker output rate
- Increased burn-out of fuel traces arriving with raw materials

[0099] The installation of a kiln SAS (either with a single axial injector or a number of injectors at or near the vessel walls), with an appropriate momentum, bluff body size and/or swirl vane angle so that a significant portion of the process gas flow is entrained into the swirling flow, before the beginning of a new plug flow zone in the rotary kiln at approximately the end of the calcination zone (Gas temperature > 1200C) is expected to promote the combustion of the unburned fuel in the process gas flow by:

- Making the O_2 concentration more uniform
- Scrubbing away a CO_2 layer that forms over the raw meal in the rotary kiln

- Exposing the unburned fuel more often to a higher O_2 concentration by stirring up the feed bed. (Although there may be practical limits as to just how much dust recirculation can be tolerated).

[00100]   This will facilitate:

- The use of lower levels of O_2 at the upper end of the rotary kiln for the same level of substitution of conventional fuel by lump fuel and hence less impact on clinker output rate
- Use of higher and /or coarser levels of lump fuel for the same level of O_2 at the upper end of the rotary kiln.

[00101]   The installation of an axial or peripheral kiln SAS is also expected to facilitate the use of petcoke with alternative fuels:

- The use of lump fuel with petcoke produces even more severe build-up of sulphates, for the reasons described above, at even modest levels of petcoke use.
- The installation of the SAS system in the kiln at the end of the calcination zone facilitates the use of higher levels of petcoke and/or a higher S grade of petcoke.

[00102]   The installation of a preheater SAS is expected to reduce the exit CO and temperature level from gas riser ducts and precalciners with alternative fuel usage:

- The introduction of lump fuel (indeed, this also happens with pulverised coal to a certain extent) to gas risers and calciners can produce increased CO and exit temperatures due to:
  - Higher volatile release rate from the fuel
  - Stratification of the O_2 supply from the kiln and the Tertiary Air Duct, leaving insufficient O_2 available locally to combust the volatiles in an excess of O_2 to produce sufficient OH radicals to facilitate CO burnout.
- This leads to the need for higher riser duct or precalciner O_2 levels, leading to increased fuel consumption and decreased clinker output rate.
- The installation of a SAS system in the precalciner that is designed for appropriate momentum, bluff body size and swirl vane angle to mix as much as possible of the gas riser duct or precalciner flow into the high momentum swirling flow(s) before the centre point of the duct is expected to:
  - Reduce stratification and CO
  - Reduce the O_2 level needed to eliminate CO
  - Give a better burnout of the coal, petcoke or lump fuel
  - Reduce exit temperature

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- Improve fuel consumption
- Improve clinker output rate by increasing the calcination rate via the removal of the CO_2 boundary layer

[00103]   The installation of a SAS is expected to reduce NOx, via reburning and staging:

- The introduction of volatiles into the process gas flow at 1000 – 1400C reduces NOx via the reburning reaction, providing there is a deficiency of O_2. The efficiency of the reburning depends on the temperature (the higher the better, 1200C being a good level) and the local stoichiometry (0.85 is preferable)
- The staging of combustion, by allowing the coal volatiles to burn sub-stoichiometrically and re-introducing the remainder of the air afterwards, reduces NOx formation from Fuel Nitrogen.
- Both reburning and staging can be used in the cement making process to reduce NOx levels and even produce "Low NOx" cement kiln systems.
- The SAS can make the strategy more effective by:
    - In the precalciner SAS, facilitating the burn out of char after the final Tertiary Air Introduction
    - In the kiln SAS variants, ensuring that, if lump fuel is used for reburning, then it is burnt out before the end of the calcination zone. In addition, the use of the kiln SAS to facilitate fuel burn-out, will also help the reburning by producing a more uniform concentration of O_2 at the upper end of the kiln.

[00104]   By installing a SAS downstream in the process gas flow from the injection point of ammonia in a plant operating the SNCR de-NOx procedure, the small amount of unreacted or "slipped" ammonia can be converted to NO, hence avoiding the dark plume formation and ammonia emission problems and allowing more ammonia to be added for a better degree of NOx reduction.

[00105]   The installation of a SAS is expected to reduce dioxins from a by-pass:

- It is being noticed that when lump fuel is fed onto the kiln feed shelf or into the calciner, the resulting poor burnout can lead to dioxins being formed in by-passes.
- The same applies to coal.

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- The potential for dioxin formation is due to unburned carbon or volatiles being carried up the by-pass and acting as drivers for the *de novo* synthesis reaction.
- The installation of a SAS system in the early part of the by-pass (in a similar manner to a calciner or gas riser) will facilitate the burn out of the unburned material and eliminate dioxin formation.

[00106] The installation of a SAS may also provide more clinker output:

- The general use of the range of SAS systems facilitates a lower O_2 level within the kiln system; lower exit gas temperatures, better combustion and better heat transfer to the solid material being processed.
- Hence as an alternative to taking up all of these advantages to their fullest extent (exploiting greater levels of fossil fuel substitution by Alternative Fuels or petcoke or seeking lower NOx levels), an increase in clinker output rate can be obtained.

[00107] In the above text, although "fuel" has been discussed, it will be understood that combustible material, char or volatile, can also arrive with raw materials. Either char may survive passage through the preheater or material with a volatile fuel content may be fed to a lower stage of a preheater or to the calciner in order to reduce episodes of volatile distillation and emission to air.

[00108] Further, although the above embodiments discuss the injection of air or gas, steam could, in principle, be injected instead of or as well as air (although requiring more momentum to achieve the same mixing effect), if conveniently available under pressure. As will be understood, steam alone will not provide the same levels of oxygen, however, this may not be important in situations where producing the mixing effect may be the more important feature of the SAS.

[00109] It will be further understood that the invention is not limited to the embodiments described herein which are merely illustrative of preferred embodiments of carrying out the invention, and which are susceptible to modification of form, arrangement of parts, steps, details and order of operation. The invention, rather, is intended to encompass all such modification within its scope, as defined by the claims, including application to kiln systems producing products other than Portland cement

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clinker. Further, the invention is not limited to the use of a SAS at only one point in a kiln system and circumstances may exist where a second (or more) SAS system will add to the advantages and/or produce different advantages.
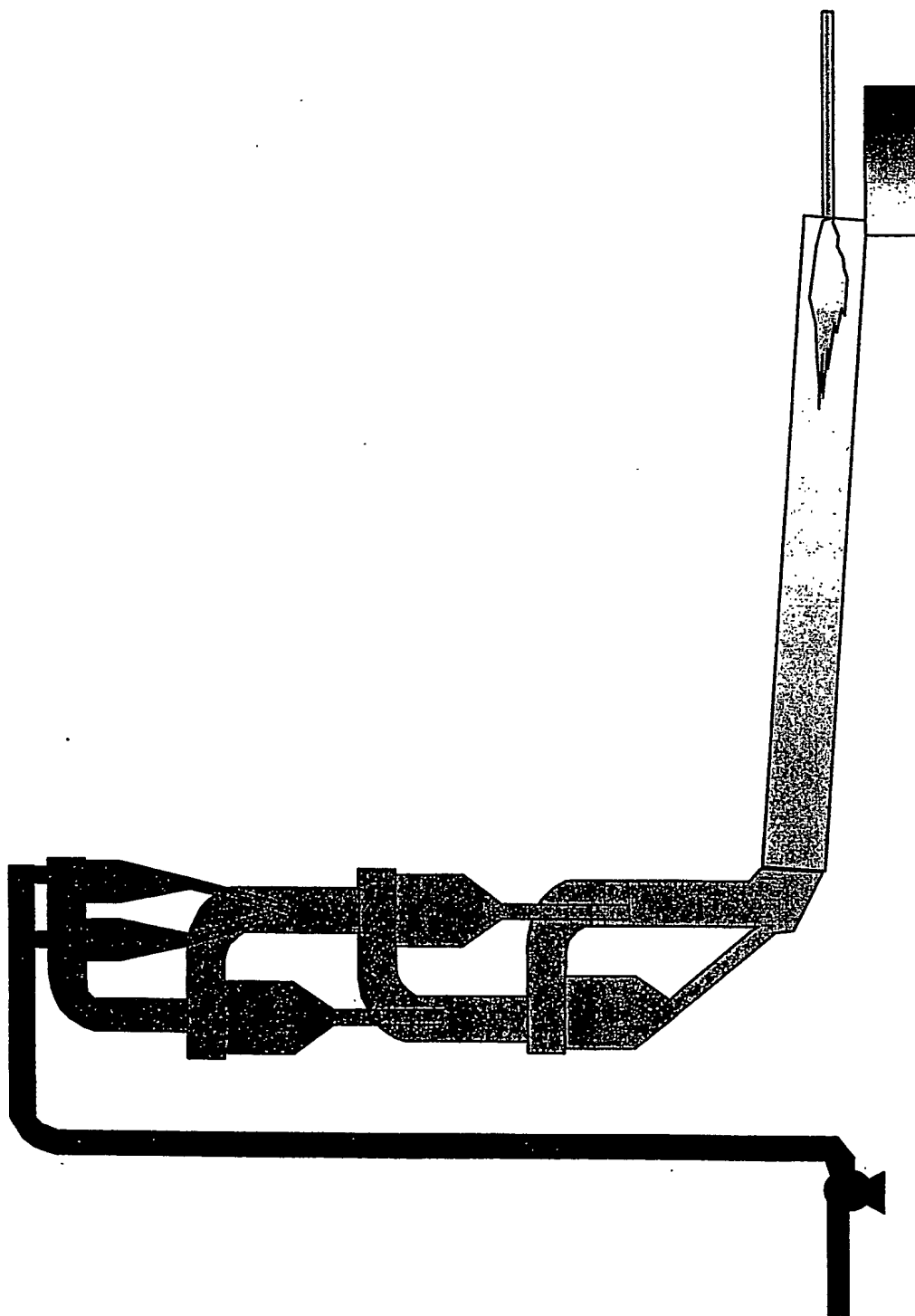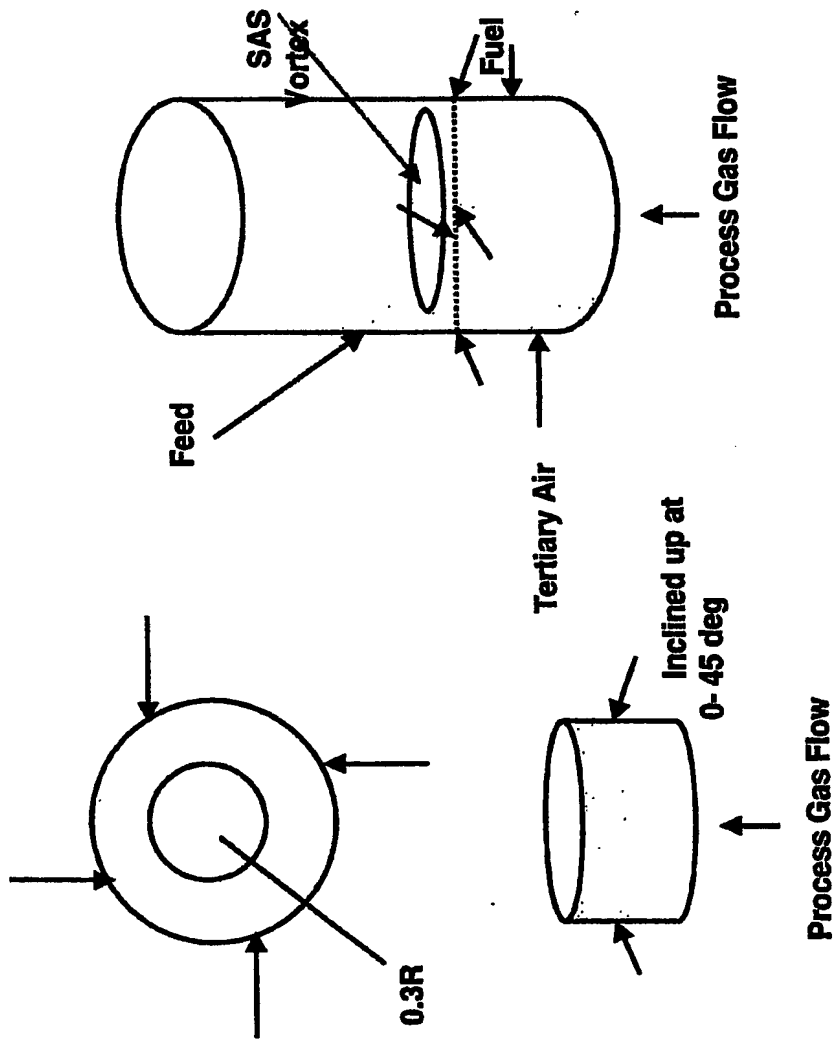
Figure 1

SAS
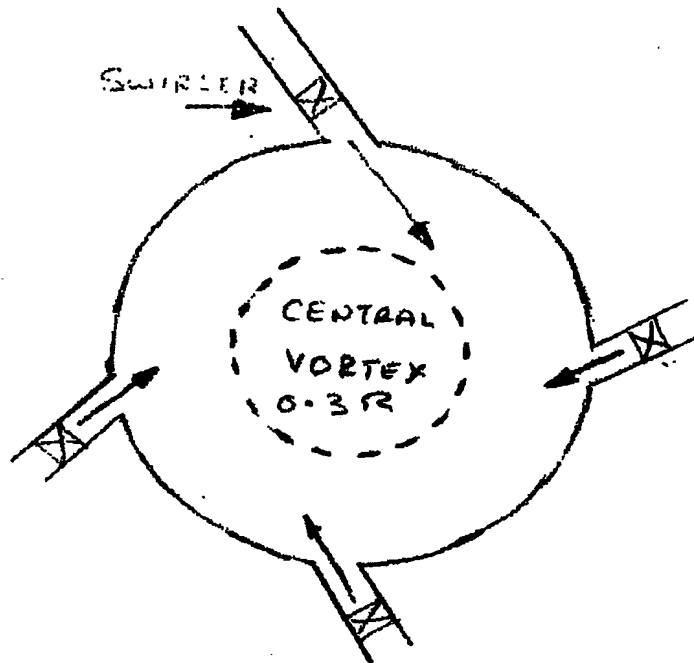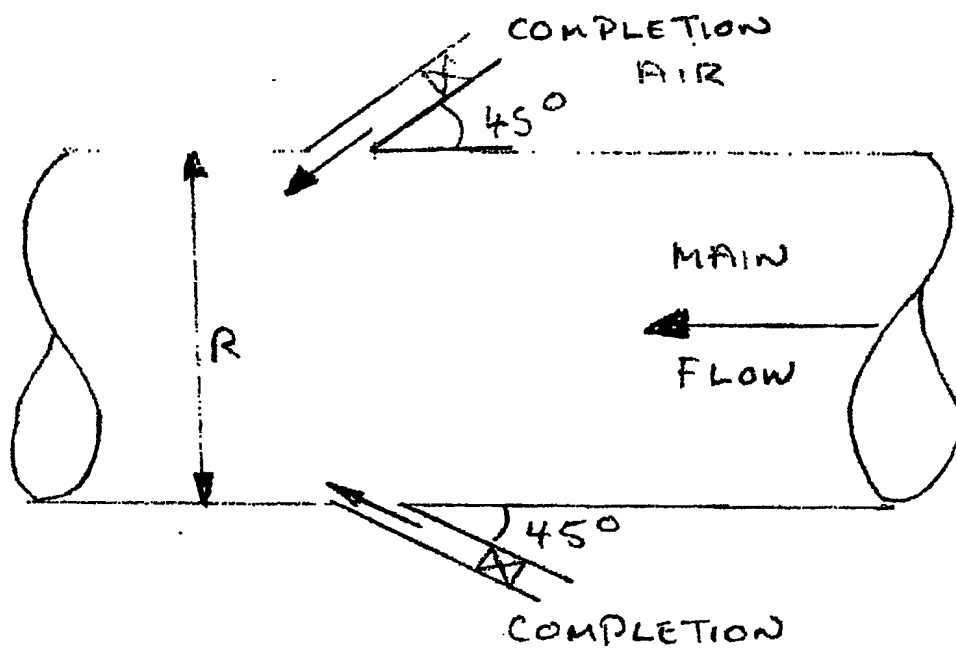Vortex
Fuel
Feed
Process Gas Flow
Tertiary Air
Inclined up at
0- 45 deg
Process Gas Flow
0.3R

Figure 2

Figure 3

Figure 4

SWIRLER
(OPTIONAL)

AIR
INJECTOR
"DIFFUSER"
(OPTIONAL)

0.2 0.6R 0.4R

R

Figure 5

Figure 6

COAL LINES

12"∅ HEADER SEE DETAIL 'A'

2700

2700

T.O.G.
EL.110.400

Figure 7

Figure 8

EL. 113.960
T.O.GRATING

EL 110.400
T.O GRATING

¢EL 114.266

¢EL 113.351

FLANGE EL.
110.913

T.O.S. EL.
105.485

SWIRL VANE

RETRACTORY

CALCINER
INSULATION

CALCINER

BLIND FLG

BALL VALVE
C/W QUICK DISCONNECT

KNIFE GATE VALVE

30° ELBOW

90° ELBOW
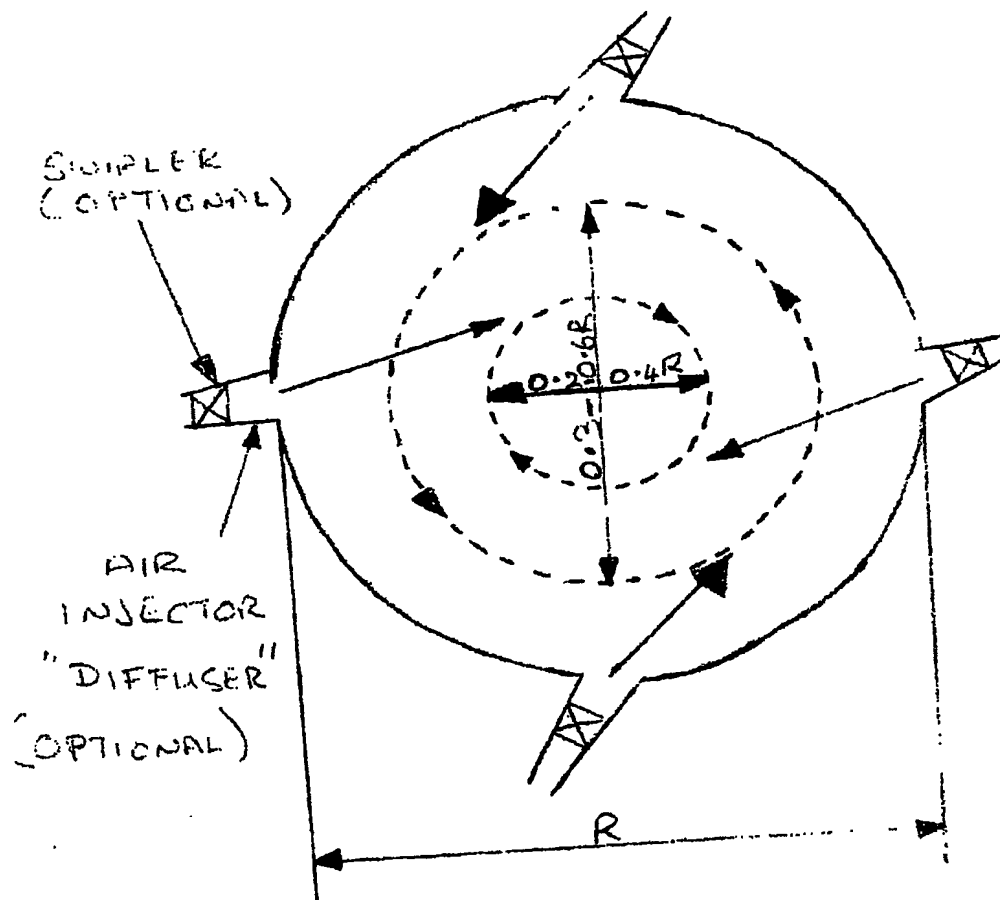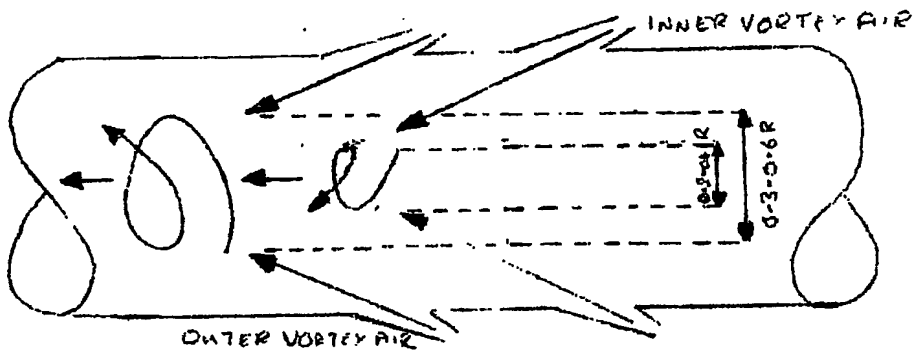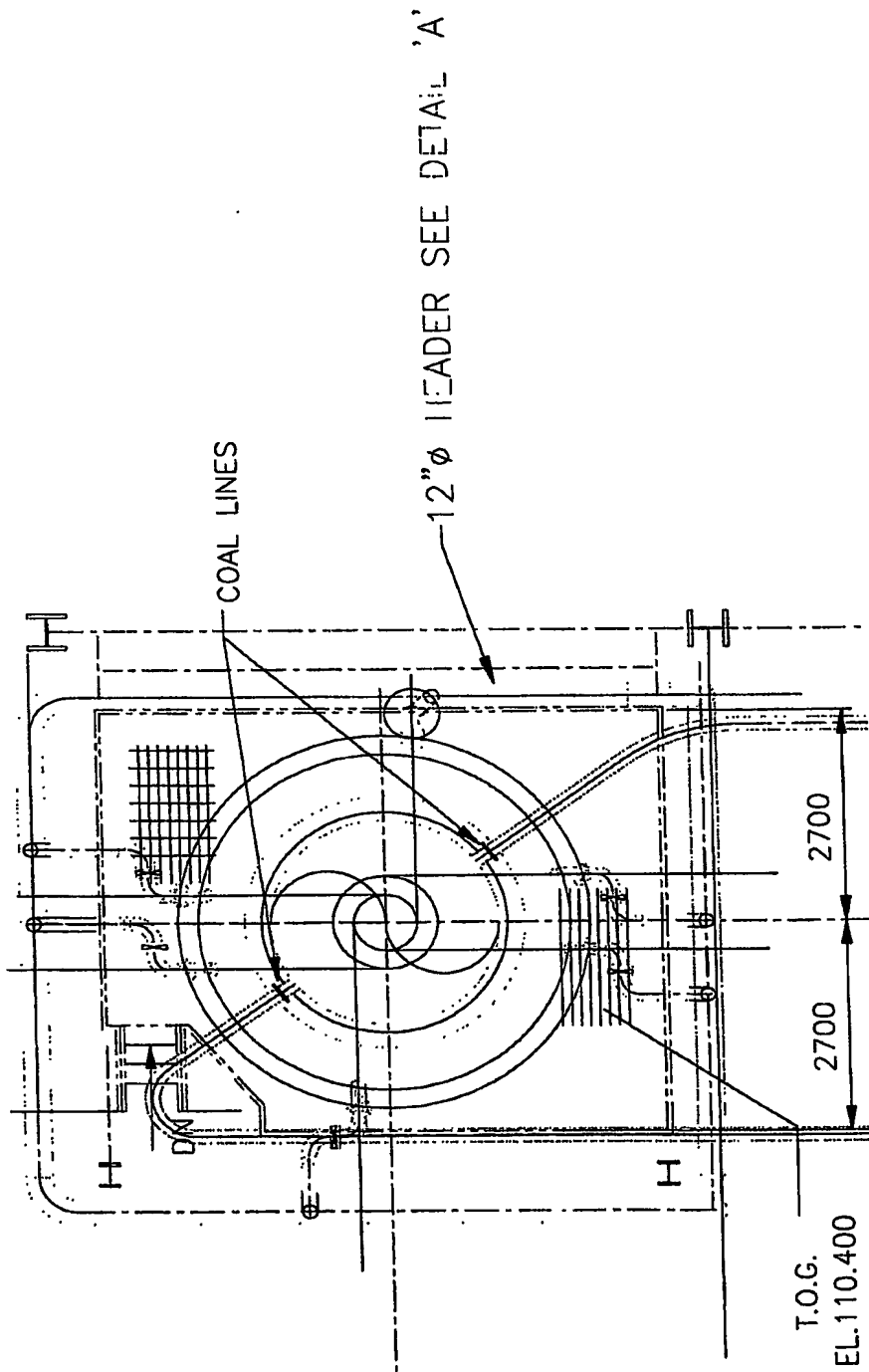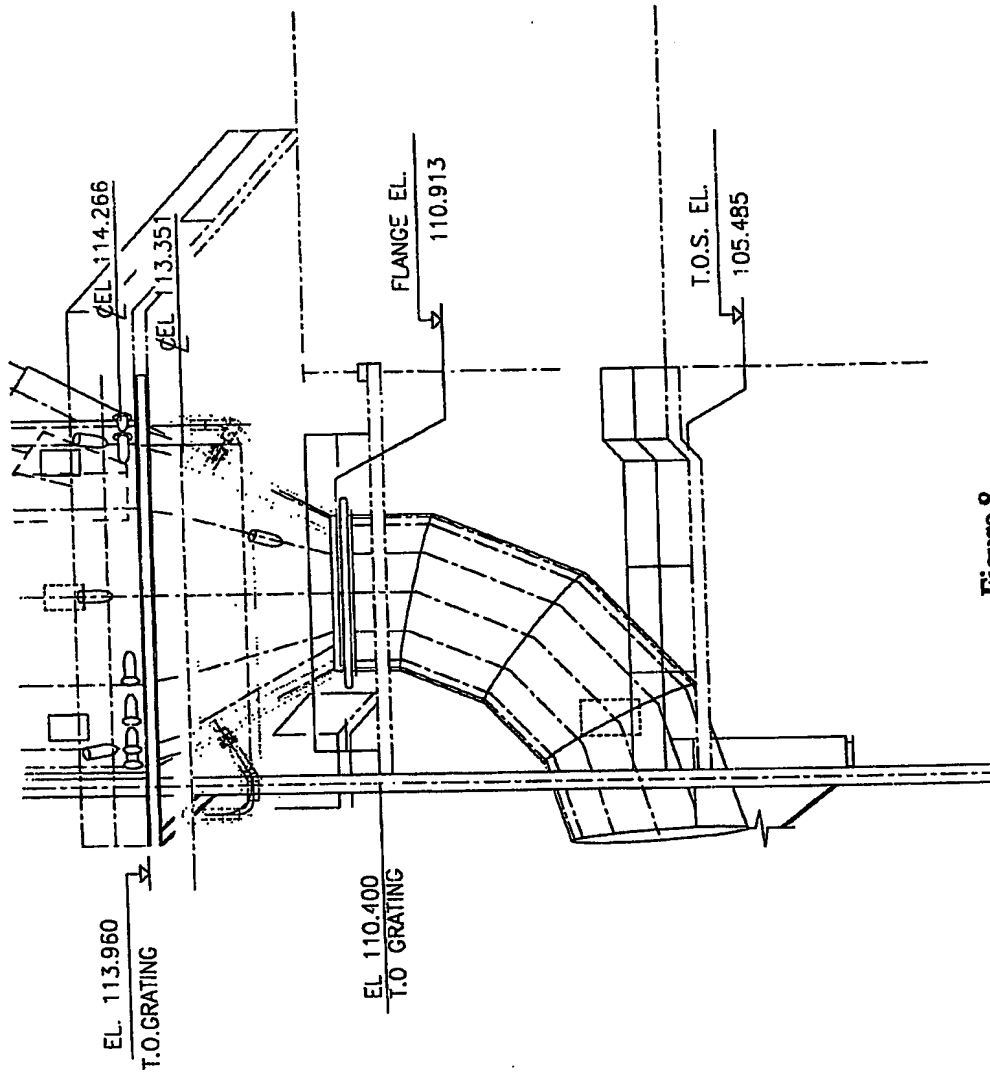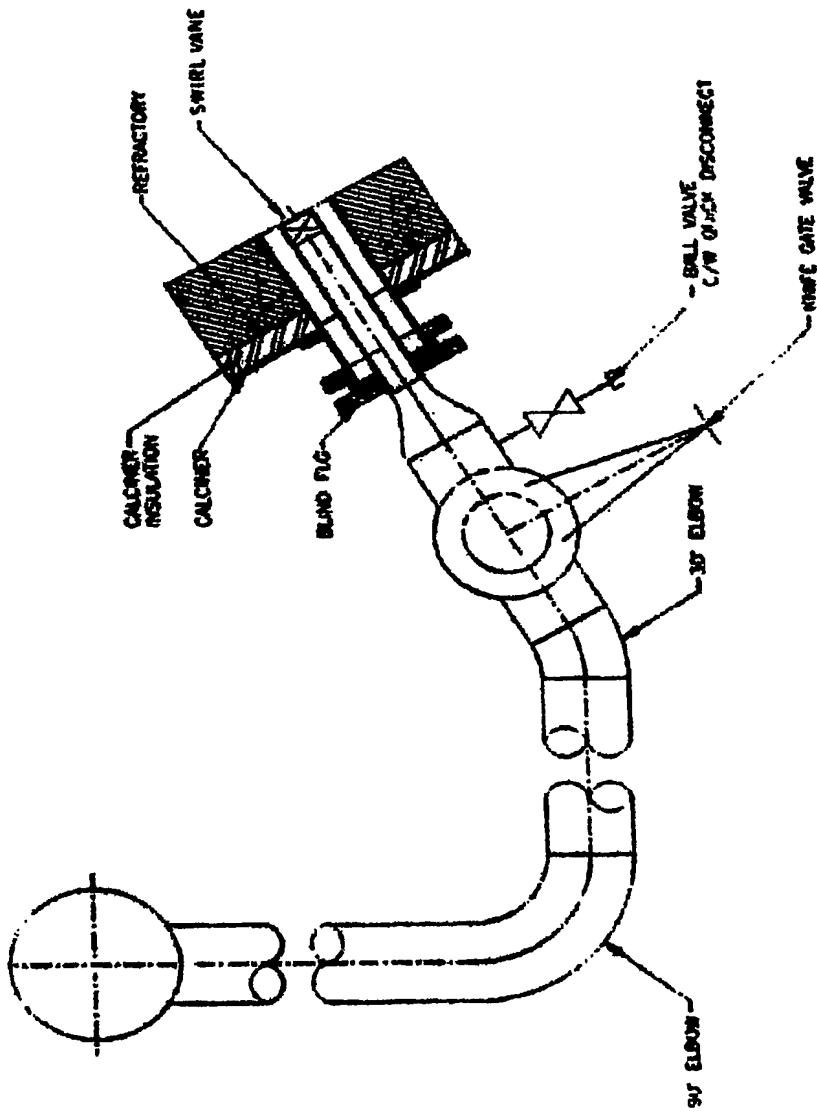
Figure 9

SAS in Preheater/Calciner Kilns and Gas Riser

SAS: 4 tangential entries on 0.3 R(10% area) inclined at 0-45 deg, for Reburn for low NOx or CO elimination

Lump Fuel on feed shelf

CO2 layer

Kiln feed shelf

SAS: 30 degree swirl vanes plus bluff body, momentum equiv designed to entrain all main kiln gas flow before impingement point, to burn out C in feed & so avoid high sulphate based build up

Lower CO, NOx

Feed

Unburnt C in feed

Gas Temperature 1200C
reasonable Tube life and good combustion

Inner Brick 1100C

Kiln gas (O2 higher at Top)

Figure 10

COMPLETION
AIR

MAIN

FLOW

SWIRL +
BLUFF BODY

Figure 11

Preheater Kiln with back end or riser pipe firing

Gas Riser SAS

Fuel into gas riser or on to hearth

KILN SAS

Feed shelf and hearth

Kiln Fuel

Clinker Cooler

Figure 12

AIR SEPARATE CALCINER KILN

Tertiary Air Duct

Calciner

Calciner Fuel

Kiln fuel

Clinker Cooler

Calciner SAS

Kiln SAS

Figure 13